SINGLE OBJECTIVE OPTIMIZATION OF EDM MACHINING ON TITANIUM WORKPIECE USING TAGUCHI METHOD

WAN MOHD ARIFF BIN WAN AZLI

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

Electrical discharge machining (EDM) is a process for shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electro-conductive materials. The objective of this paper is to investigate how the polarity, peak current, pulse on duration, pulse off duration and servo voltage in EDM effect on material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). The effectiveness of EDM process with titanium alloy (Ti-6Al-4V)through electrical discharge machining (EDM) using copper tungsten (CuW)as an electrode.It is observed that copper tungsten (CuW) is most suitable for use as the tool electrode in EDM of Ti-6Al-4V .Better machining performance is obtained generally with the electrode as the cathode and the workpiece as an anode. In this research, a study was carried out on the influence of the parameters such as polarity, peak current, pulse on duration, pulse off duration and servo voltage. The surface quality that was investigated in this experiment was surface roughness using perthometer machine. Material removal rate (MRR) and electrode wear (EW) in this experiment was calculated by using mathematical method. The result of the experiment then was collected and analyzed using MINITAB software. This was done by using the technique of design of experiments (DOE) and technique such as ANOVA analysis. This analysis was purposed to select the optimal machining condition for use in confirmation test.

ABSTRAK

Nyahcaselektrikmemesin (EDM) ialahsatu proses untukmembentuklogamkerasdanmembentuklubang-lubangberbentukkompleksolehhakisanarkadalamsemuajenisbahan yang mengalirkanelektrik. Tujuankajianiniialahuntukmenyiasatfaktorkekutuban, aruspuncak, denyut di tempoh, denyutdarivoltantempohdanvoltan servo yang memberikesankepadakadarpemesinanbahan (MRR), kadarkehausanalat (TWR) dankekasaranpermukaan (SR). Keberkesanan proses nyahcaselektrikmesin (EDM) dengan (Ti-6Al-4V)melaluinyahcaselektrikmemesin (EDM) menggunakan (CuW) sebagaisatuelektrod. Diperhatikan yang (CuW) paling sesuaiuntukkegunaansebagaielektrodalatdalamnyahcaselektrikmesin (EDM) bagi (Ti 6Al 4V) .Prestasipermesinan yang baikdiperolehipadaumumnyadenganelektrodsebagaikatoddanbahansebagaianod. Dalampenyelidikanini, satukajiantelahdijalankandipengaruhioleh parameter sepertikekutuban, aruspuncak, denyut di tempoh, denyutdarivoltantempohdanvoltan servo. Kualitipermukaandalameksperimeninidiperolehikekasaranpermukaannyadenganmenggunakanmesinperthometer. Kadar pemesinanbahan (MRR) dankehausanalat (TWR) dalameksperimeninidikiradenganmenggunakankaedahmatematik. Hasileksperimenkemudiandipungutkandandianalisismenggunakanperisian MINITAB.Inidilakukandenganmenggunakankaedahdesaineksperimen (DOE) dantekniksepertianalisis ANOVA.Analisisinibertujuanuntukmemilihkeadaanpermesinan yang optimum bagikegunaandalamujianpengesahan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOL

μ	Unit microsecond
$\varnothing$	Diameter
Ω	Ohm
W_{pi}	Sample initial weight
W_{pf}	Sample final weight
W_{ei}	Electrode initial weight
W_{ef}	Electrode final weight
T	Time in minute
R_a	Measured to quantitatively evaluate how EDM parameters affect the surface finish

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machine
CuW	Copper Tungsten
MRR	Material Removal Rate
EWR	Electrode Wear Ratio
SR	Surface Roughness
ANOVA	Analysis of Variance
DC	Direct Current
DOE	Design of Experiments
WRW	Workpiece Removal Weight
EWW	Electrode Wear Weight
OA	Orthogonal Array
PV	Predicted Value
CI	Confidence Interval

CHAPTER 1

INTRODUCTION

1.1 ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. Electrical discharge machining process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporizing. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using electrical discharge machining such as dies and moulds.. The moving of tool electrode, up and down, in Z axis only introduces new dielectric fluid into the cavity of the workpiece. When the electrode is cycled down, it pushes out the contaminated oil. Injection flushing is where the dielectric fluid is forced down through a flushing hole in the tool electrode.

The workpiece material used in this study is a titanium alloy and the tools is using copper tungsten that hard and can be cut the titanium alloy. The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). The control parameters optimization for individualmachining characteristic is concerned with separately maximize the material removal rate, separately minimize the tool wear ratio and separately obtained a good surface finish. There are many input parameters which can be varied in the EDM process which have different effects on the EDM machining characteristics.

In this paper, the use of the Taguchi method to determine the electric discharge machining process parameters. This is because the Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality at the design stage (Y. M. Zhang, R. Kovacevic, and L. Li, (1996)), S. C. Juang, Y. S. Tarng, and H.R. Lii (1998)). By using this method, we can determine and find the suitable parameter to optimize the electrical discharge machine on titanium workpiece. This project is to investigate the optimum parameter required for MRR, EWR and SR by using Taguci method.

1.2 IMPORTANCE OF RESEARCH

The important of doing this research are:-

1) Improve the quality surface finish of the cut metal.
2) Improve efficiency of production process by increasing the machining process performance and lowering the manufacturing cost.
3) Minimize the time and cost of production process by using L18 orthogonal array because it suitable experimental plan to optimize the machining parameters easier than than using full factorial experimental plan.
4) Enhance the production rate.
5) Analysis of Variance (ANOVA) is being used for the data analysis of maximizing the material removal rate (MRR), minimizing electrode wear ratio (EWR) and minimizing surface roughness (SR).

1.3 PROBLEM STATEMENT

During the machining process, wear will occur on the electrode. This will affect the machining efficiency and cost. Other than that, the optimum parameter is also problems occur in this project. The optimum parameter can affect and meanwhile optimize the EDM process. For rough machining that related to material removal rate (MRR), minimum MRR will decrease the machining productivity. For intermediate machining that related to electrode wear ratio (EWR), higher EWR will affect more on dimensional precision of the machined workpiece. Beside that, for fine machining related to surface roughness (SR), higher surface roughness will produce a very poor surface integrity.

1.4 OBJECTIVE OF RESEARCH

The objective of this thesis is to optimize the surface roughness (SR), electrode wear ratio (EWR) and material removal rate (MRR) by taguci method and to discuss on the
significant factors by using analysis of variance (ANOVA).

1.5 SCOPE OF RESEARCH

The research is limited to single machining characteristics control parameters optimization. The machining characteristics mentioned are material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) because each type of EDM machining i.e. rough machining, intermediate machining or fine machining requires single machining characteristic of control parameters optimization.

1.6 RESEARCH FLOW CHART

The flow chart of this research is illustrated in figure 1 below:-

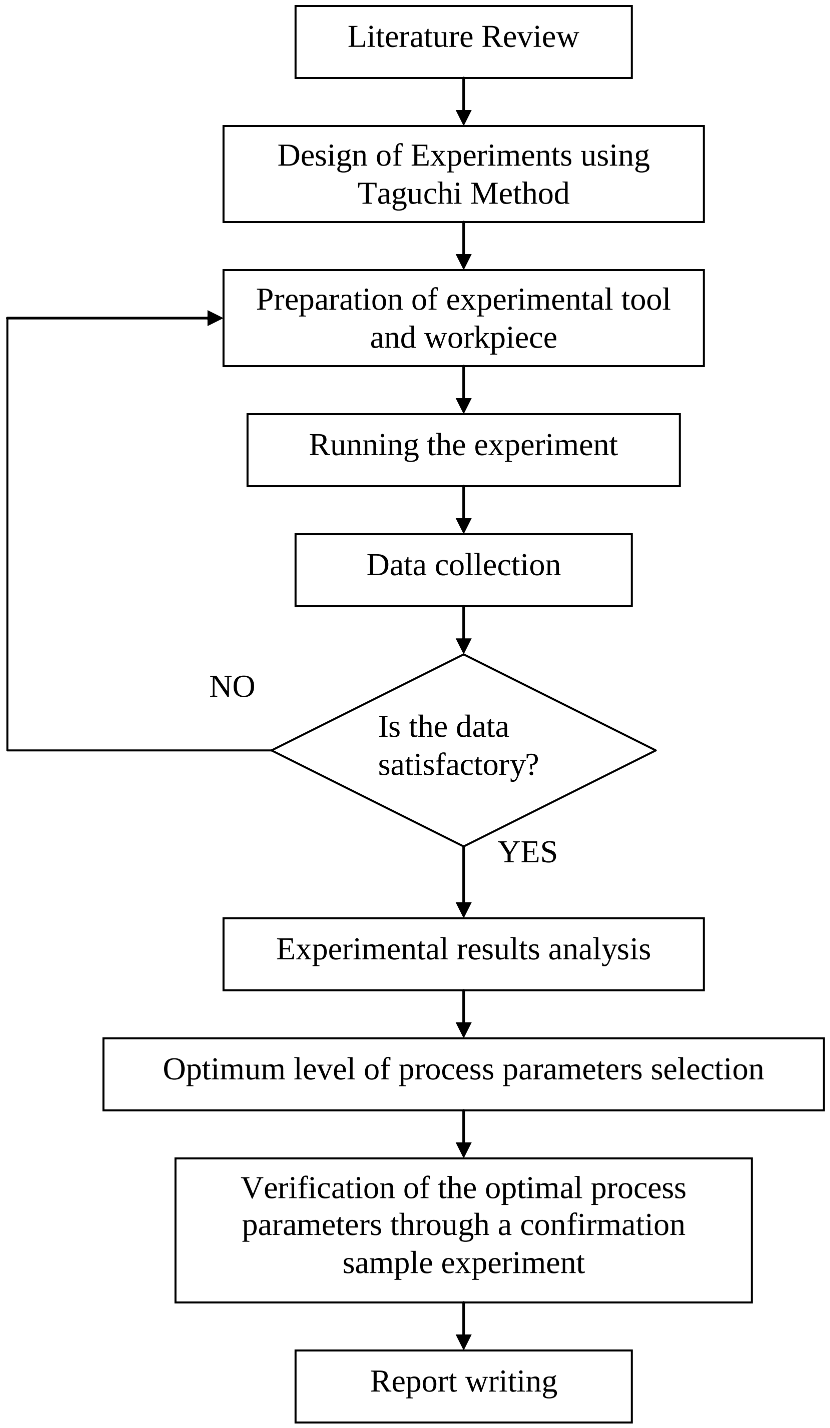

Figure 1: Research Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discuss on some literatures about EDM process, parameters and methods involved in this project. A literature review is a body of text that aims to review the critical points of current knowledge and studies related to the project. In 1970, the English scientist, Priestley, first detected the erosive effect of electrical discharges on metals. More recently, during research (to eliminate erosive effects on electrical contacts) the soviet scientists, Lazarenko and Lazarenko, decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943, they announced the construction of the first spark erosion machining. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and an improved form is being used in many current application. The EDM process can be compared with the conventional cutting process, except that in this case, a suitably shaped tool electrode, with a precision controlled feed movement is employed in place of the cutting tool and the cutting energy is provided by means of short duration electrical impulses. It thus plays a major role in the machining of dies, tools, etc., made of tungsten carbides, stellites or hard steels. Alloys used in the aeronautics industry, for example, hastalloy, nimonic, etc., could also be machined conveniently by this process. EDM is also used to machining of exotic materials, refractory metals and hard enable steels. This process has an added advantage of being capable of machining complicated components and making intricate shapes. Most of the surgical components are being machined by this process since EDM is one of the unconventional processes which can produce better surface quality.

2.2 PRINCIPLES OF EDM OPERATION

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece.

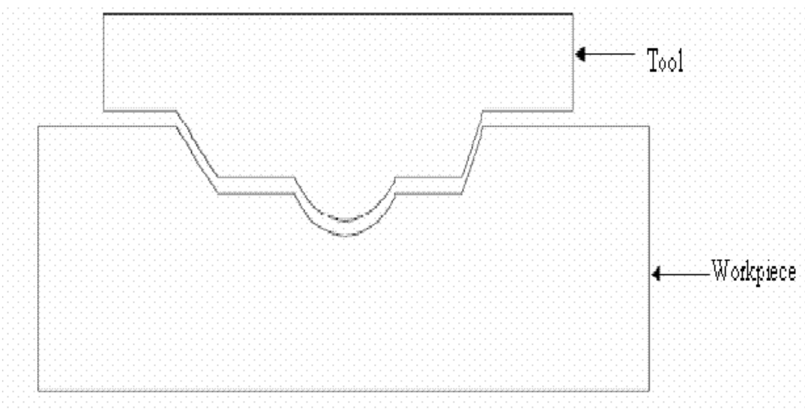

Figure 2.0 : Tool shape and corresponding cavity formed on work piece after EDM Operation

Source: Lazarenko :R-C circuit EDM [EDM](2008)

Thus, a replica of the tool surface shape is formed on the work piece as shown in figure 2.0. If the tool is held stationary, machining would stop at this stage. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the work piece.

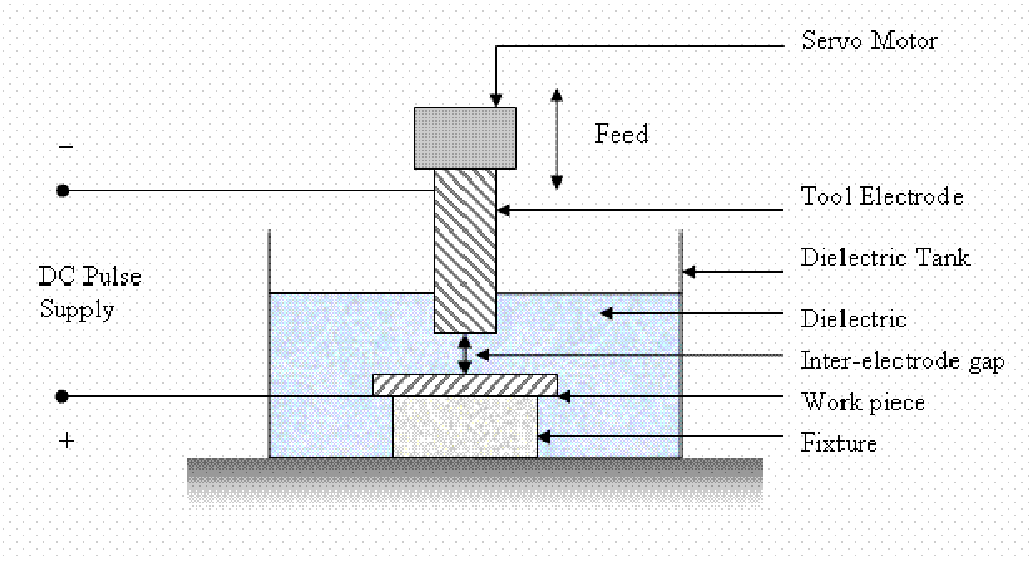

Figure 2.1 :Schematic diagram of basic EDM System

Source: Lazarenko :R-C circuit EDM [EDM](2008)

The schematic of an EDM machine tool is shown in figure 2.1.The tool and the work piece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the work piece is generally provided for maintaining a constant gap distance between the tool and the work piece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the work piece, the tool is moved downward towards the work piece to maintain a constant inter-electrode gap. The tool and the work piece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap. Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the work piece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300 cubic mm/min can be achieved during EDM.

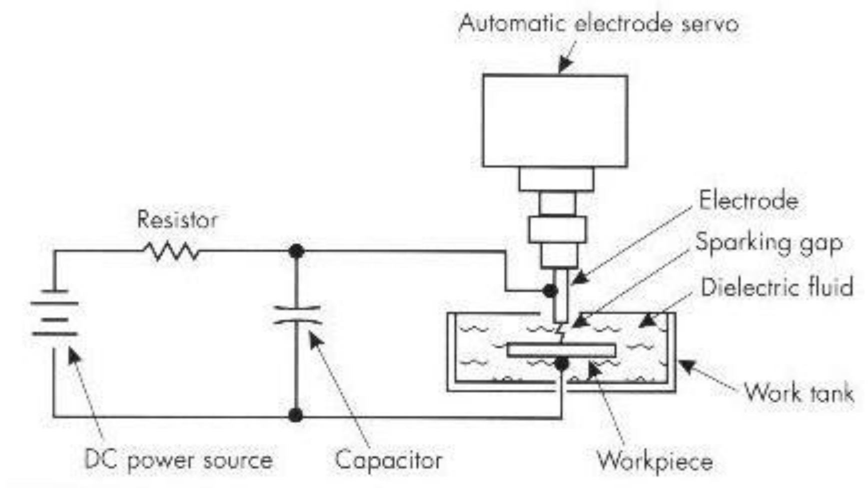

Figure 2.2 :Spark initiation in EDM process

Source: Anti TRIZ Journal [EDM](2009)

Figure 2.2 shows the workpiece is mounted on the table of the machine tool and the electrode is attached to the ram of the machine. A DC servo unit or hydraulic cylinder moves the ram (and electrode) in a vertical motion and maintains proper position of the electrode in relation to the workpiece. The positioning is controlled automatically and with extreme accuracy by the servo system and power supply. During normal operation the electrode never touches the workpiece, but is separated by a small spark gap. During operation, the ram moves the electrode toward the workpiece until the space between them is such that the voltage in the gap can ionize the dielectric fluid and allow an electrical discharge (spark) to pass from the electrode to the workpiece.

The benefits of EDM include:

i) EDM is a non-contact process that generates no cutting forces, permitting the production of small and fragile pieces.

ii) EDM machines with built-in process knowledge allow the production of intricate parts with minimum operator intervention.

iii) Burr-free edges are produced.

Limitations of EDM are :

There are quite a number of problems still to be solved to enable the process to be adopted on an extensive process.

1. Lower Material Removal Rate (MRR) , Poor Surface Quality(SQ) are the real time EDM process limitations. In other words, maximizing the MRR, minimizing the surface roughness value [9] are the real time EDM process objectives.
2. The wear rate on the electrode is considerably higher. Sometimes it may be necessary to use more than one electrode to finish the job.
3. The work piece should be electrically conductive to be machined.
4. The energy required for the operation is more than that of the conventional process and hence will be more expensive.
5. Environmental concerns associated with the process have been a major drawback of EDM. The dielectric fluid used in EDM is the primary source of pollution from the process. Hydrocarbon based oils are the most commonly used EDM dielectric. Dielectric wastes generated after machining are very toxic and cannot be recycled. Also, toxic fumes are generated due to high temperature chemical breakdown of dielectric during machining. The use of oil as the dielectric fluid also makes it necessary to take extra precaution to prevent fire hazards. Since an environment friendly alternative for replacing the EDM process is not available, changing or totally eliminating the liquid dielectric medium provides a feasible solution.

2.3 DIE-SINKING EDM MACHINE

Die-sinking EDM machines are also known as ram or vertical EDMs. Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was kerosene. Figure 2.1 show the schematic diagram of basic EDM system.

Die-sinking EDM have four sub-systems that are:

i) DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.
ii) Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.
iii) Consumable electrode.
iv) Servo system to control infeed of the electrode and provide gap maintenance.

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionise when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.

Generally kerosene and deionised water is used as dielectric fluid in EDM. Tap water cannot be used as it ionises too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

Kerosene dielectric gives lower relative tool wear values compared with the other dielectrics for a low to medium range of current.

The functions of the dielectric fluid are to:

i) Act as an insulator between the tool and the workpiece.

ii) Act as coolant.

iii) Act as a flushing medium for the removal of the chips.

2.4 TITANIUM ALLOY WORKPIECE

The workpiece used in this research was Ti6Al4V, a popular material for medical instruments and aeronautic industries. This titanium alloy has high melting temperature (16048^{0}C) and low thermal conductivity (0.016 cal/s cm 8^{0}C). It can be classier as a difficult-to-cut material, not suitable for traditional machining. The specimen dimensions were diameter 25mm and thickness 6mm. In addition, the electrode material was copper tungsten with dimensions of diameter 5 mm and length 26mm.

2.5 TAGUCHI METHOD

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use (Wiley, 1991). An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence (S. Fraley, M. Oom, B. Terrien, and J. Z. Date, 2006).

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables. The Taguchi method has been criticized in the literature for its difficulty in accounting for interactions between parameters. Another limitation is that the Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study. Furthermore, since the Taguchi methods deal with designing quality rather than correcting for poor quality, they are applied most effectively at early stages of process development (UnitekMiyachi Group, (1999)).

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the